

University of Groningen

Distributed coordination and partial synchronization in complex networks

Qin, Yuzhen

DOI:
[10.33612/diss.108085222](https://doi.org/10.33612/diss.108085222)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2019

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):
Qin, Y. (2019). *Distributed coordination and partial synchronization in complex networks*. University of Groningen. <https://doi.org/10.33612/diss.108085222>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Distributed Coordination and Partial Synchronization in Complex Networks

Yuzhen Qin



The research described in this dissertation has been carried out at the Faculty of Science and Engineering, University of Groningen, the Netherlands.

disc

The research reported in this dissertation is part of the research program of the Dutch Institute of Systems and Control (DISC). The author has successfully complete the educational program of DISC.

ISBN (book): 978-94-034-2222-0
ISBN (e-book): 978-94-034-2233-6



university of
 groningen

Distributed Coordination and Partial Synchronization in Complex Networks

PhD thesis

to obtain the degree of PhD at the
 University of Groningen
 on the authority of the
 Rector Magnificus, Prof. C. Wijmenga,
 and in accordance with
 the decision by the College of Deans.

This thesis will be defended in public on

Friday 6 December 2019 at 14:30 hours

by

Yuzhen Qin

born on 20 August 1990
 in Chongqing, China

Supervisors

Prof. M. Cao

Prof. J.M.A. Scherpen

Assessment committee

Prof. J. Cortés

Prof. F. Pasqualetti

Prof. A.J. van der Schaft

To my family

献给我的家人

妻子葛杉杉、
母亲董红、父亲秦有清

Acknowledgments

My journey as a Ph.D. student in Groningen is soon coming to an end. The past four years could not have been so memorable without the help and support of my colleagues, friends, and family.

I would like to express the depth of my gratitude to my supervisor Prof. Ming Cao, who has taught me a lot on many aspects within and beyond research. He taught me how to write precisely and think critically. He pointed out my shortcomings so frankly, which greatly helped me become aware of them and start to make changes. It is his unique style of supervision that benefited me a great deal and made my Ph.D. journey so unforgettable. I also want to thank my second supervisor Prof. Jacquelin M.A. Scherpen for reading and commenting on my thesis, and the valuable advice from time to time.

My special admiration goes to Prof. Brian D.O. Anderson at Australian National University. He is so kind and knowledgeable. I frequently felt that he was like a magician, because he was able to recall and locate potentially helpful books and papers published decades ago. Every discussion with him was inspiring. I am very grateful to all the precious advice, help, and encouragement he gave me along the way. I also would like to thank Dr. Yu Kawano, from whom I have learned a lot on mathematically rigorous writing. I want to thank Dr. Mengbin (Ben) Ye for the collaboration we had and all the help he offered. I also want to thank Oscar Portoles Marin for many technical discussions on neuroscience.

I thank Alain Govaert and Dr. Xiaodong Cheng for being my paranymphs. Also, many thanks go to Alain for translating the summary of this thesis into Dutch. I also would like to express my thanks to my friends including the aforementioned ones. Many of them have already left Groningen. In the past few years, we discussed together, traveled together, had dinners together, and played games and cards together. My life in Groningen could not have been so joyful without their accompany and help. Those moments I spent with them will certainly become beautiful memories in my life.

I also thank Prof. Jorge Cortés, Prof. Fabio Pasqualetti, and Prof. Arjan J. van

der Schaft for assessing my thesis and providing constructive comments.

Last but not least, I would like to thank my family for the endless love and support. I thank my wife Shanshan for joining me in Groningen. Without her accompany and care, my life here could not have been so cheerful. I want to express my sincere gratitude to my parents in Chinese. 感谢我的母亲，是她多年来对我的信任、鼓励与支持让我有勇气不断进步；感谢我的父亲，是他一直默默的付出与支持让我心无旁骛。没有他们，就没有今天的我。

Yuzhen Qin
Groningen,
November, 2019

Contents

Acknowledgements	vii
1 Introduction	3
1.1 Background	3
1.1.1 Distributed Coordination Algorithms	4
1.1.2 Synchronization and Brain Communication	5
1.2 Contributions	8
1.3 Thesis Outline	11
1.4 List of Publications	12
1.5 Notation	13
2 Preliminaries	15
2.1 Probability Theory	15
2.2 Graph Theory	16
2.3 Stochastic Matrices	17
I Stochastic Distributed Coordination Algorithms: Stochastic Lyapunov Methods	19
3 New Lyapunov Criteria for Discrete-Time Stochastic Systems	23
3.1 Introduction	23
3.2 Problem Formulation	24
3.3 Finite-Step Stochastic Lyapunov Criteria	28
3.4 Concluding Remarks	35
3.5 Appendix: Proof of Lemma 3.4	35
4 Stochastic Distributed Coordination Algorithms	37
4.1 Introduction	37
4.2 Products of Random Sequences of Stochastic Matrices	39

4.2.1	Convergence Results	40
4.2.2	Estimate of Convergence Rate	46
4.2.3	Connections to Markov Chains	47
4.3	Agreement Induced by Stochastic Asynchronous Events	48
4.3.1	Asynchronous Agreement over Strongly Connected Periodic Networks	52
4.3.2	A Necessary and Sufficient Condition for Asynchronous Agreement	54
4.3.3	Numerical Examples	57
4.4	A Linear Algebraic Equation Solving Algorithm	59
4.5	Concluding Remarks	62
4.6	Appendix: An Alternative Proof of Corollary 4.2	63

II Partial Synchronization of Kuramoto Oscillators: Partial Stability Methods 65

5	Partial Phase Cohesiveness in Networks of Kuramoto Oscillator Networks	69
5.1	Introduction	69
5.2	Problem Formulation	71
5.3	Incremental 2-Norm	73
5.4	Incremental ∞ -Norm	76
5.4.1	Main Results	76
5.4.2	Comparisons with Existing results	81
5.5	Numerical Examples	83
5.6	Concluding Remarks	87
6	New Criteria for Partial Stability of Nonlinear Systems	89
6.1	Introduction	89
6.2	New Lyapunov Criteria for Partial Stability	90
6.2.1	System Dynamics	91
6.2.2	Partial Asymptotic and Exponential Stability	93
6.2.3	Examples	100
6.3	Partial Exponential Stability via Periodic Averaging	105
6.3.1	A Slow-Fast System	105
6.3.2	Partial Stability of Slow-Fast Dynamics	107
6.3.3	A converse Lyapunov Theorem and Some Perturbation Theorems	111
6.3.4	Proof of Theorem 6.5	118
6.4	Concluding Remarks	123

7 Remote Synchronization in Star Networks of Kuramoto Oscillators	125
7.1 Introduction	125
7.2 Problem Formulation	126
7.3 Effects of Phase Shifts on Remote Synchronization	128
7.3.1 Without a Phase Shift	128
7.3.2 With a Phase Shift	131
7.3.3 Numerical Examples	135
7.4 How Natural Frequency Detuning Enhances Remote Synchronization .	139
7.4.1 Natural frequency detuning $u = 0$	141
7.4.2 Natural frequency detuning $u \neq 0$	143
7.4.3 Numerical Examples	150
7.5 Concluding Remarks	151
8 Conclusion and Outlook	153
Bibliography	156
Summary	173
Samenvatting	175

